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CUTTING ICE WITH A CONTINUOUS HIGH-PRESSURE WATER JET

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Hanover, New Hampshire

August 1973

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13. ABSTRACT

In a study of the possible techniques of cutting ice by an "icecutter", it was clarified that, in addition to the mechanical devices for cutting and breaking down the ice, it is feasible to utilize a high-pressure water jet. The possibility of the utilization of such jets is particularly important for cutting relatively thick ice (from 0.5m and more) since the mechanical means (disk cutters, etc.) are fairly complicated. During the movement of the icecutter, from a hydrocompressor mounted on the ship, through shaped nozzles, we feed continuous high-pressure jets with which a number of parallel blocks are cut.

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NOTICE

CUTTING ICE WITH A CONTINUOUS HIGH-PRESSURE WATER JET

Trudy Arkticheskogo i Antarkticheskogo Nauchno-Issledovatel'skogo Instituta (Transactions of Arctic and Antarctic Scientific-Research Institute), 300, Leningrad, 1971, pp 168-176

Z.I. Shvaishtein

In recent years, in the USSR and in foreign countries, considerable attention is being paid to the conduct of winter navigation in the freezing nonarctic seas, on the rivers and canals. The expansion of the navigation periods in the Arctic also has great importance.

With the increase in the winter shipments, unique importance is acquired by the effectiveness of the operation of icebreakers, seagoing and river vessels during navigation through ice. Therefore, simultaneously with an increase in the power and an improvement in the designs of icebreakers and vessels for ice navigation, we are developing new means and methods for weakening and disrupting the ice, with the aid of which navigation through ice can be considerably facilitated.

Specifically, when operating in stationary ice, a very effective means of overcoming the ice is the icecutter [8], i.e. a new type of vessel designed for creating a channel clear of ice.

The model tests conducted by us in the test basin of the AASRI (Arctic and Antarctic Scientific-Research Institute) and also the advance design development conducted by the Central Planning Design Bureau of the USSR Ministry of the Maritime Fleet confirmed the basic feasibility and the economic advantage of creating such a ship for operating at the approaches to ports, in the estuaries of rivers, etc.

One of the main operations performed by the icecutter is the cutting, from the ice field ahead of the vessel, of ice blocks. In a study of the possible techniques of cutting ice by the "icecutter", it was clarified that, in addition to the mechanical devices for cutting and breaking down the ice, it is feasible to utilize a high-pressure water jet. The possibility of the utilization of such jets is partic' larly important for cutting relatively thick ice (. ›m 0.5 m and more) since the mechanical means (disk cutters, etc.) are fairly complicated.

During the movement of the icecutter, from a hydrocompressor mounted on the ship, through shaped nozzles, we feed continuous high-pressure jets with the aid of which we cut a number of parallel blocks.

From the pressure of the bow's surface on the ends of the ice strips, they are broken off; after this they are slid by the guiding rib-strips (mounted on the ship bottom) under the ice pack beyond the limits of the channel, which turns out to be smooth and open.

In addition to the cutting and disintegration of ice for the passage of ships, the high-pressure jets can also be employed in various areas of ice engineering (for protecting port and hydraulic installations, structures of ice, etc.).

At the present time the hydraulic technique of breaking down and cutting is utilized chiefly in the develcpment of minerals, in construction and other branches of industry.

The investigations of the emission of constant water jets at high velocity from shaped nozzles having various sections have been the subject of many reports by both foreign and domestic authors; morever, the initial studies in this field have been made as early as the end of the last century by D. Rayleigh.

D. Rayleigh theoretically studied a jet of ideal liquid and established that as a result of the rotational-symmetrical fluctuations, the disintegration of a jet occurs when the wave length of fluctuations exceeds the length of the jet's circumference. We are aware of the following relationship of the wave length of jet's fluctuations on its diameter:

$$l_{obt} = \pi d \sqrt{2} = 4.44d,$$

where l = wave length and d = diameter of jet.

K. Weber utilized D, Rayleigh's theory for viscous fluids and established the relationship of the length of the continuous part of the jet on the conditions of outflow and their physical properties.

The theoretical study of K. Weber was performed on the basis of experimental data obtained by A. Heinlein who investigated the breakdown of a jet at various outflow rates (ranging from 3 to 75 m/sec). A. Heinlein distinguished three forms of jet disintegration: 1) axial-symmetrical breakdown of jet into drops, 2) wave-like form of jet and 3) atomization of jet.

N.P. Gavyrin studied the outflow of water jets at rates up to 30 m/sec and established that the length of the nondisintegrating part of a jet increases with an increase in velocity and then decreases. He proposed a formula for the decrease in velocity at the jet axis with distance from nozzle.

$$V = \frac{145 V_o d_o}{L}$$

It is apparent from the equation that the constant velocity of the jet axis is retained up to L = 145d.

Of special interest are the theoretical and experimental studies having been conducted over many years in the laboratory of ultrahigh pressure physics at the USSR Academy of Sciences, certain results of which have been employed by us in the present report.

L.F. Vereshchagin, A.A. Semerchan, A.I. Firsov, F.M. Filler and others [1-6] performed very important research on the hydrodynamics of a liquid jet flowing from a nozzle at pressures of 1000-2000 atm. These studies laid the basis for the Soviet theoretical and experimental studies of the outflow of continuous high-pressure jets.

These studies required the development of special installations which would permit the ejection of a liquid through nozzles at a velocity considerably exceeding the speed of sound through water.

Thus with the aid of the equipment developed in the Institute of High-Pressure Physics of the USSR Academy of Sciences, we succeeded in obtaining water jets preliminarily compressed to 2000-2500 atm on their outflow from a round shaped opening with a diameter of 0.2-1.2 mm.

Based on the curve shown in Fig. 1 [1], we can judge the power which is expended in ejecting the jets under various operating conditions of a hydrocompressor. As is obvious from this graph, for each of the diameters of the hydrocompressor's piston, the power increases in proportion to pressure. During movement of the piston forward, the force F = PS is acting on it. The work per cycle equals PSl, where S = piston area, l = its stroke while P = pressure in the compressor.

The measurements of the powers at various piston diameters indicated that:

1) At unchanging diameter, the power increases in proportion to pressure; and

2) at constant pressure, the power increases in proportion to the cross section.

Since the rate of water outflow is a function of pressure developed by the hydrocompressor, for determining this function we can utilize the D. Bermoulli equation, which for an ideal incompressible fluid has the following form:

$$P + \frac{\rho V^2}{2} = \text{const.}$$

In Fig. 2 (curve 1), we have shown the dependence of outflow rate of a high-pressure jet obtained on the basis of this formula. In the case of an ideal (nonviscous) but compressible fluid, Bernoulli's equation has the form:

$$\frac{V_1^2}{2} + \int_0^{P_1} \frac{dp}{\rho} = \frac{V_2^2}{2} + \int_0^{P_2} \frac{dp}{\rho}.$$

Knowing the dependence of ρ on P, we can calculate the outflow rate of a jet at various pressures in the hydrocompressor, with consideration of the water's compressibility.

With the aid of P. Bridgeman's data concerning the compressibility of water, we determined the dependence of the jet's velocity on pressure, and we constructed curve 2 in Fig. 2 [6]. As is obvious from this curve, up to a pressure of 2000-3000 atm, the compressibility of water has practically no influence on the rate of its outflow and in conformity with Bernoulli's equation:

$$V = 14\sqrt{P},$$

where P is assumed in kg/cm^2 while V is adopted in m/sec.

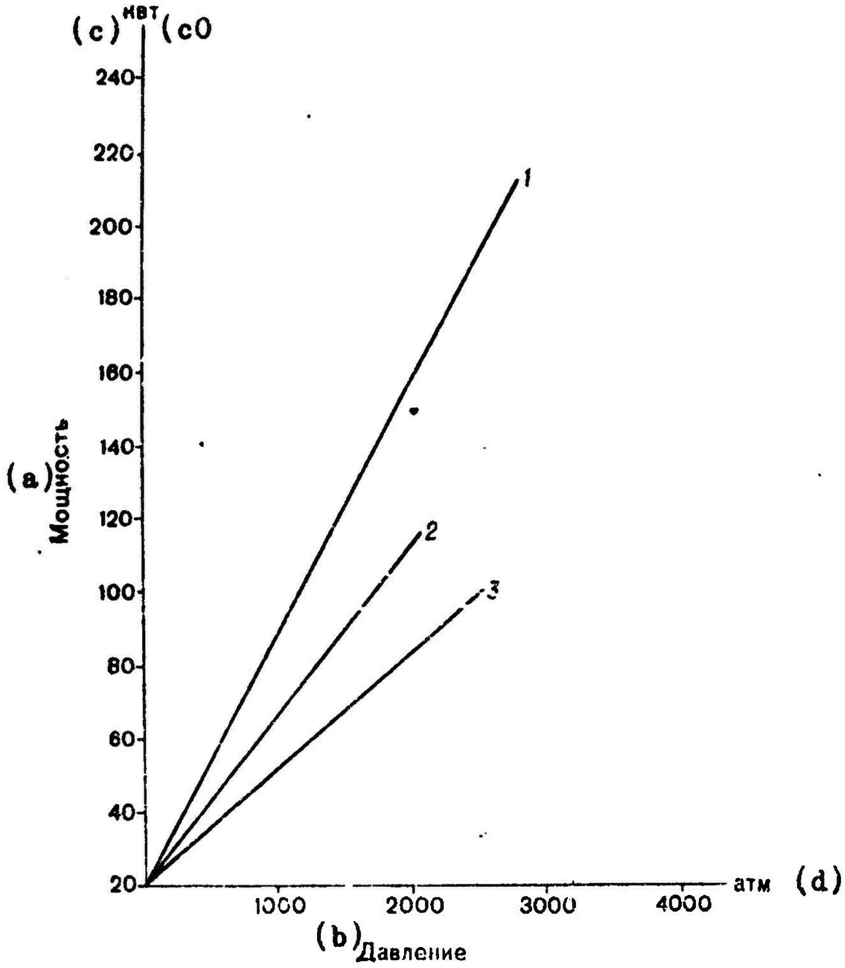

Fig. 1. Force Expended to Eject a High-Pressure Water Jet at Various Piston Diameters: 1 - 33 mm; 2 - 27 mm; and 3 - 22 mm. Key: a. Force; b. Pressure; c. kw; and d. atmospheres

The determination of the most important parameter of a jet, i.e. its velocity, presents great theoretical and experimental difficulties since it varies through time and has varying values at different points.

The main cause for its inconstancy through time is the pulsation of pressure in the receiver during the hydraulic compressor's functioning. It is just for this reason that the rate computed with formula $V = 14\sqrt{P}$ is also averaged through time and permits us to judge its value only approximately.

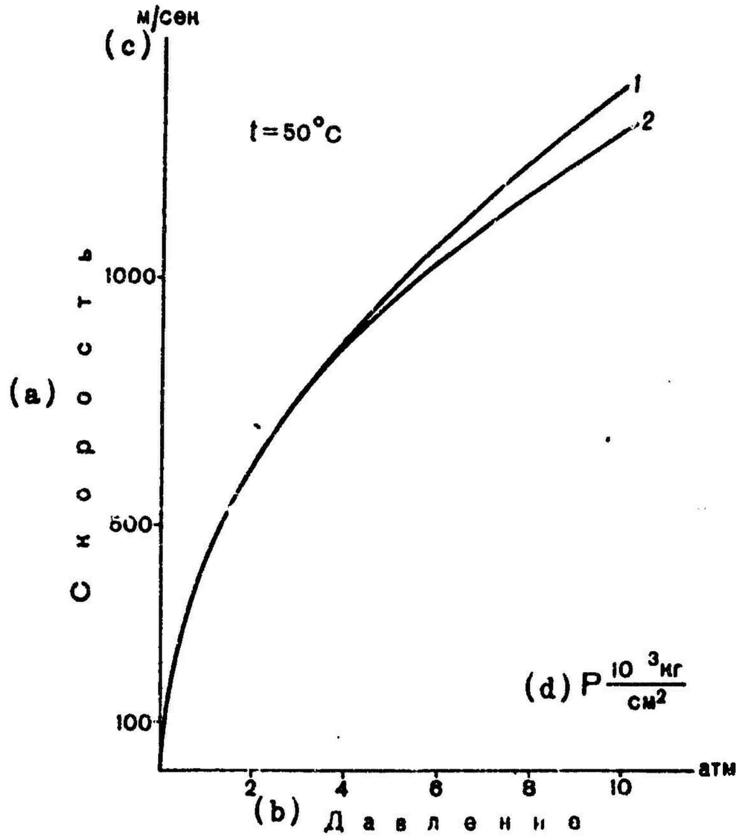

Fig. 2. Outflow Velocity of High-Pressure Water Jets at Temperature of 50° and Varying Pressure in Hydraulic Compressor: 1 - without considering compressibility; and 2 - with allowance for compressibility. Key: a. Velocity; b. Pressure, atm; c. m/sec; and d. $P\frac{10^3 gk}{cm^2}$

We have indicated in Fig. 3 the theoretical and experimental curves for jet outflow rates through a nozzle [4].

Extensive theoretical and experimental studies on the utilization of high-pressure jets for breaking down rocks were conducted by the Mining Institute imeni A.S. Skachinskiy [7], the Institute of Mining Affairs at the Ural Branch of USSR Academy of Sciences, the Leningrad Mining Institute and others.

In principle, certain general concepts obtained from these studies are also valid for the purposes of disintegrating and cutting of ice. The most general concepts convince us that for ice cutting, the dynamic specific pressure of the water jet should somewhat exceed the ice's compressive strength

$$P > \sigma_{compr.} K.$$

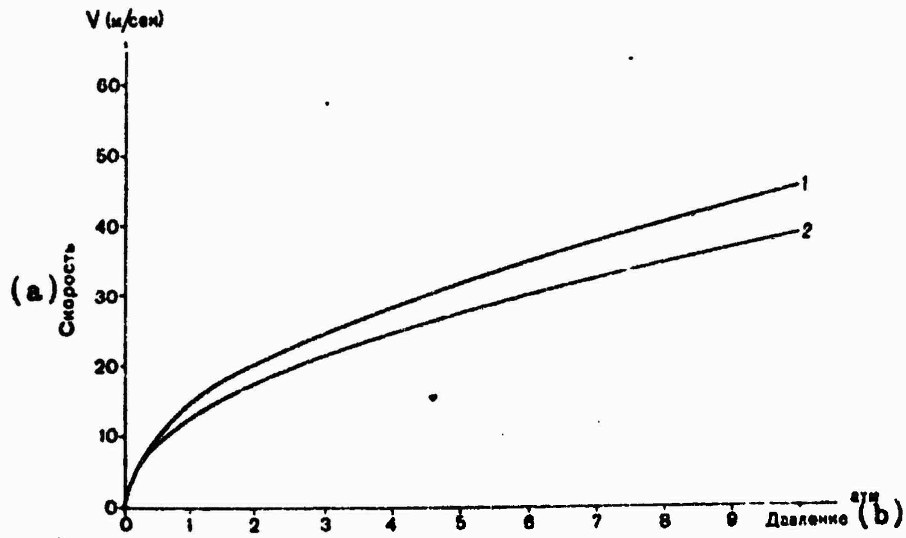

Fig. 3. High-Pressure Jet Outflow Rate vs. Pressure: 1 - theoretical; and 2. experimental. Key: a. Velocity, V(m/sec); and b. Pressure, atm.

Having assumed σ_{compr} (fresh ice's ultimate strength at uniaxial compression perpendicularly to the freezing surface)

equalling 50 kg(force)/cm^{2}K (coefficient of ice breakdown) equalling 0.5, we find that for the breakdown of ice, the dynamic pressure of jet

$$P = 50 \cdot 0.5 = 25 \text{ kg(force)/cm}^2.$$

The necessary dynamic jet pressure at the nozzle edge can be determined with the following formula:

$$P_o = P\left(\frac{L}{l_n}\right)^{0.85},$$

where l_n = length of continuous jet sector equalling about

50d$_o$(d_o = nozzle diameter; L = jet's length (from nozzle edge to bottom of slot), from which

$$P_o = P\left(\frac{L}{50d_o}\right)^{0.85}.$$

Based on the studies conducted at the Leningrad Mining Institute, fine high-pressure jets preserve an adequately destructive foce at

$$L = (400\text{-}500)d_o.$$

Thus at distance L = 750 mm, diameter of nozzle fitting

$$d_o \approx \frac{750}{500} \simeq 1.5 \text{ mm.}$$

In this way, $P_o = 25\left(\frac{75}{50 \cdot 0.15}\right)^{0.85}$, $\log P_o = 2.503$,

from which we have P_o = 320 kg/cm^2.

The approximate calculations show that under the conditions indicated, for cutting the ice, use can be made of a nozzle setup developing a pressure of around 300-400 kg/cm^2. Obviously the effectiveness of ice cutting will be higher at a great dynamic jet pressure, which with the given diameter of the outlet orifice on the fitting can be increased owing to a higher pressure which is being developed by the pump arrangement.

Certain of the results from the tests conducted on cutting ice with continuous high-pressure water jets should be regarded as the first stage in the investigations. The tests were conducted with the participation of the author in the ice-research laboratory of AASRI (Arctic and Antarctic Scientific-Research Institute) in cooperation with the Hydraulics Department at the Leningrad Institute of Railroad Transportation Engineers imeni Academician V.N. Obraztsov (LIRTE).

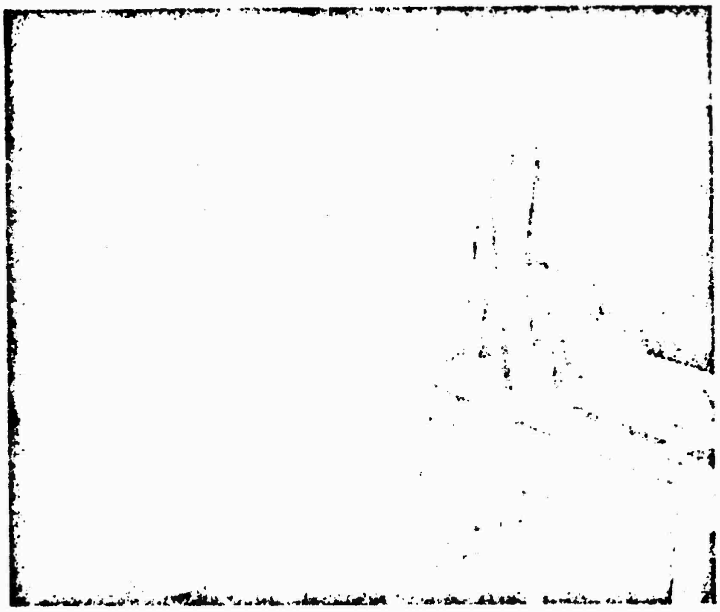

Fig. 4. Form of Jet During Cutting of Ice.

For the conduct of the tasks, at the Hydraulic Department of LIRTE, in 1965 we organized a new laboratory where we designed and installed special equipment and fixtures. The main equipment included: a pumping installation, a mobile stand, nozzles with various diameters of outlet orifices and a system for remote control of turning the nozzles and adjusting the pumping pressure. The stand on which the ice samples were mounted consisted of a cart on wheels and of a support frame fastened to bearings to the side walls of the cart.

The ice specimens were placed on the mobile stand which was set up in such a way that the distances from the nozzle to

the ice surface were 20, 40, 60 and 80 cm. The ice cutting was done with various nozzles with outlet orifice diameters comprising 1, 1.5, 2 and 2.5 mm.

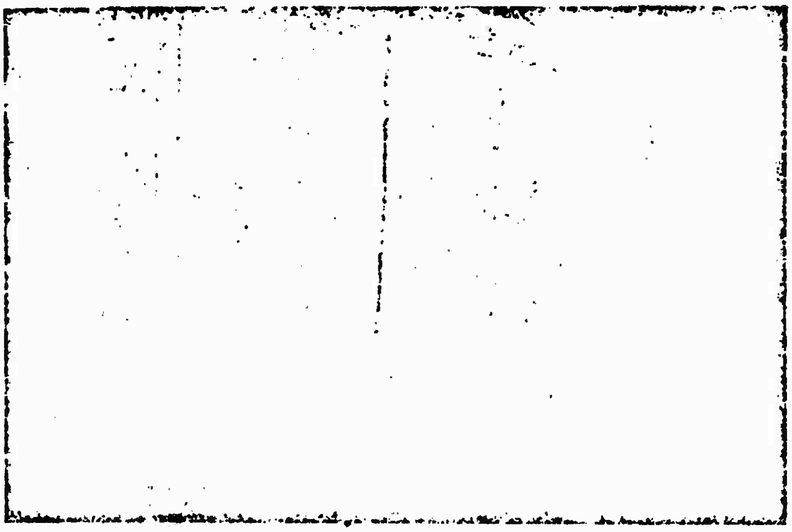

Fig. 5. Form of Ice Block with Several Cuts.

We have shown in Fig. 4 the form of jet during cutting of an ice block while Fig. 5 depicts an ice sample with several incisions. The results obtained have shown that ice cutting with continuous high-pressure water jets is extremely effective.

BIBLIOGRAPHY

[1] Vereshchagin, L.F., Semerchan, A.A., Isaykov, V.K., and Firsov, A.I., "Hydraulic Installation for Obtaining a Supersonic Liquid Jet Flow," Pribory i Tekhnika Eksperimenta (Instruments and Experimental Techniques), No 1, 1959.

[2] Vereshchagin, L.F., Semerchan, A.A., and Sekoyan, S.S., "On Question of Fragmentation of High-Speed Jet," Zhurnal Teoreticheskoy Fiziki (Journal of Theoretical Physics), Vol 29, No 1, 1959.

[3] Vereshchagin, L.F., Semerchan, A.A., and Filler, F.M., "On Question of Discontinuity of Velocity in a Water Jet," Journal of Theoretical Physics, Vol 28, No 2, 1958.

[4] Vereshchagin, L.F., Semerchan, A.A., Filler, F.M., and Galaktionov, V.A., "Certain Studies in a Water Jet Emerging from a Nozzle Under Pressure up to 2000 Atm," Bull. of USSR Acad. Sci., No 1, 1957.

[5] Vereshchagin, L.F., Semerchan, A.A., Filler, F.M., and Kuzin, N.I., "Distribution of Momentum in Continuous High-Speed Liquid Jet," Journal of Theoretical Physics, Vol 28, No 9, 1958.

[6] Vereshchagin, L.F., Semerchan, A.A., Firsov, A.I., Filler, F.M., and Galaktionov, V.A., "Certain Investigations into the Hydrodynamics of a Liquid Jet Flowing from a Nozzle Under Pressure up to 1500 Atm," Journal of Theoretical Physics, Vol 26, No 11, 1956.

[7] Zelenin, A.N., Veselov, G.M., Konyashin, Yu.M., and Sharimov, V.S., "Research Findings on Application of Water Jet of Sonic and Supersonic Velocity from Disintegration of Rocks," Gornyye Mashiny (Mining Machines), No 2, 1958.

[8] Peschanskiy, I.S., and Shvayshteyn, Z.I., Opisaniye i printsip raboty ledorezokhoda (Description and Operating Principle of Icecutter), Publ. of Arctic and Antarctic Scientific-Research Institute, Leningrad, 1966.